Altair Unmanned Aircraft System Achieves Demonstration Goals

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In the early morning of 15 November 2005, the unmanned Altair aircraft returned to Gray Butte Airfield, north of Los Angeles, Calif., after completing an 18.4-hour mission over the eastern Pacific Ocean. The flight was the last in a series undertaken by the U.S. National Oceanic and Atmospheric Administration (NOAA) in its Unmanned Aircraft System (UAS) Demonstration Project. The successful flight series has helped start the era of unmanned flights in service of environmental goals. Altair cruised at altitudes in the lower stratosphere (13 kilo-meters; ~43,000 feet), collecting atmospheric data with a 140-kilogram payload of both remote and in situ instruments.

NOAA has recognized that UAS technology will improve its ability to meet scientific and operational objectives in the coming years. Operating sensor payloads on a UAS fleet could play a crucial role in the detection and attribution of climate change, improvement of weather predictions, management of water resources, monitoring and evaluation of ecosystems and sanctuaries, and atmospheric and oceanic research. UAS platforms have the potential to carry instrument payloads to remote locations in a manner that could not otherwise be achieved with conventionally piloted aircraft.

NOAA initiated the demonstration project, which was a cooperative effort undertaken with General Atomics Aeronautical Systems, Inc. (GA-ASI, San Diego, Calif.) and NASA, as an effort to acquire experience with a key UAS platform and dedicated payload. As a partner with NOAA, NASA helped with project management, flight safety, and airspace coordination. NOAA provided the majority of funds to support the project. The success of this project will help NOAA and NASA identify the most useful objectives and strategies to pursue with UAS technology in the future.

Altair Platform and Payload

Altair is a high-altitude long-endurance UAS, able to reach altitudes of 13–15 kilometers and stay aloft for more than 20 hours carrying a payload of at least 300 kilograms. Altair UAS technology is a seamless combination of an autonomous aircraft, redundant control systems, high-speed satellite and radio communication, and ground-based pilots and sensor operators.

The sole Altair aircraft has a 26-meter wingspan and an 11-meter fuselage length, and is made largely of composite materials (see Figures 1 and 2). Altair's rear-mounted turboprop engine provides a true airspeed of approximately 175 knots at a cruise altitude of 13 kilometers, which yields a 6600-kilometer range for a 20-hour flight. GA-ASI manufactured Altair, an extended-wing version of their Predator B UAS line, as part of NASA's Environmental Research Aircraft and Sensor Technology program.

The Altair payload as listed in Table 1 was integrated into the forward section of the Altair fuselage (see Figures 2 and 3), which also contains the satellite communications antenna. An external sampling probe was mounted on the starboard fuselage for the in situ instruments to obtain ambient air. Upper and lower fuselage areas were modified with openings to accommodate the viewing requirements of the remote instruments and

Fig. 1. The Altair in flight at three-kilometer altitude over the Channel Islands National Marine Sanctuary off the coast of California on 16 November 2005. The electro-optical infrared sensor protrudes below the forward fuselage.

Fig. 2. The Altair with its fuselage payload bay open at Gray Butte Airfield in April 2005. The sampling instruments are located inside the fuselage nose along with the gimbaled satellite antenna. The gas-sampling probe is visible on the left of the fuselage in this view. The small forward boom is used for sensing wind direction. The small opening at the tip of the nose is a camera port used by the pilots. Also visible above the rear fuselage is the engine intake and propeller.

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Table 1. Altair Instrument Payload

Scientific Instruments	Technique	Observables
Gas Chromatograph (GC) (in situ)	Gas chromatography	Sulfur hexafluoride (SF_6), nitrous oxide (N_2O), and halogenated gases: CFC-11, CFC-12, and halon-1211.
Ozone (OZ) (in situ)	Ultraviolet absorption	Ozone
Ocean color (OC) (remote)	7-band optical radiance detection	Chlorophyll-*a*
Passive Microwave Vertical Sounder (PMVS) (remote)	Microwave and infrared sensor suite	Temperature and moisture profiles, and cloud parameters
Operational Instruments		
Digital Camera System (DCS)	High-resolution true-color digital camera (nadir view)	Surface mapping and monitoring
Electro-Optical Infrared sensor (EO/IR)	Visible and infrared sensors with remote pointing capability	Surface mapping and monitoring
Research Environment for Vehicle-Embedded Analysis on Linux (REVEAL)	Flexible aircraft systems interface with satellite connectivity	GPS, aircraft parameters, instrument payload parameters

the digital camera system (DCS). The electro-optical infrared (EO/IR) sensor, used for imaging objects away from the aircraft, was mounted below the fuselage to maximize viewing. The aircraft engine supplied the required payload power (~1700 watts). The instruments were controlled and monitored in flight via the radio and satellite links.

Science and Operational Objectives

The Altair scientific instruments were chosen for their potential role in contributing to NOAA's Strategic Plan as it pertains to climate and weather (http://www.spo.noaa.gov/). For example, all of the gases measured in situ on Altair are radiatively active in the atmosphere,

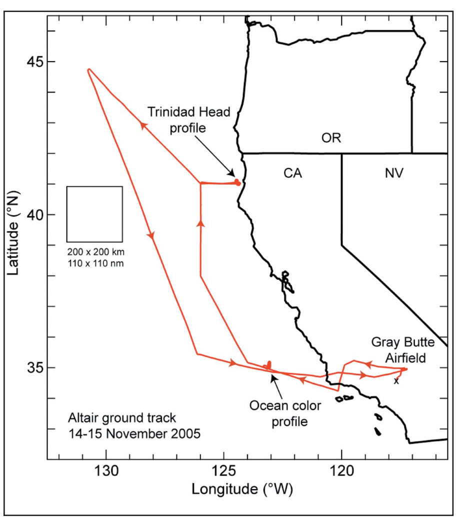

Fig. 3. The Altair ground track for the 18.4-hour flight on 14–15 November 2005. Altair returned to Gray Butte early because of a fuel management concern. Landing fuel reserves indicated that the flight could have been extended by several hours. The two locations of the ascent and descent altitude profiles are also indicated.

have been increased by human activities, and thus contribute to anthropogenic climate forcing. The abundances of the measured halogenated gases influence the chemical loss of ozone because they contain chlorine and bromine atoms. A goal of the Altair flights was to demonstrate that precise and accurate in situ measurements of trace gases could be obtained from a UAS.

Remote sensing of ocean color provides high-resolution measurements of chlorophyll *a* in the upper layers of the ocean. Chlorophyll *a* is a measure of the primary productivity of the upper ocean layer, which affects all ocean life. A goal of the Altair flights was to measure ocean color over a range of altitudes over a calm ocean surface. The profiles obtained will help address how the atmosphere and aerosols affect ocean color measurements from satellites.

Altitude profiles of temperature and water vapor from the passive microwave vertical sounder (PMVS) are of interest in measuring low-level moisture, or 'atmospheric rivers,' headed towards the United States from the tropics. These rivers often cause devastating flooding in the mountainous regions along the western U.S. coast.

The Altair operational payload instruments were chosen to demonstrate mapping, monitoring, and surveillan ce capabilities. NOAA is required to map the nation's coastal boundary, to monitor ecosystems in marine sanctuaries, and to conduct surveillance for a range of activities such as fishing within the U.S. exclusive economic zone. Currently, marine sanctuaries include more than 47,000 square kilometers of water and land and may expand by 311,000 square kilometers in the northwestern Hawaiian Islands. Demonstration objectives for the DCS were shoreline mapping and along-shore and inland feature characterization for habitat mapping and ecosystem monitoring. Objectives for the EO/IR system were day/night fishing surveillance and enforcement, and marine mammal surveys.

The Altair UAS platform provides extended operational capability over crewed aircraft, allowing enhanced mapping and monitoring missions. The value of future long-duration UAS flights will depend, in part, on the ability to control and monitor onboard instrumentation, and to transfer data to ground-based users during flight. The Research Environment for Vehicle-Embedded Analysis on Linux (REVEAL) system is a prototype instrument interface designed to meet these research needs while minimizing cost and payload weight.

Altair Flights

Three Altair test flights for payload and aircraft evaluation were completed from Gray Butte Airfield in April 2005. The test flights included the full payload and reached a maximum altitude of 13.6 kilometers and 4.8-hour duration. The scientific and operational flights began on 7 May 2005 with a 6.5-hour flight to the Channel Islands National Marine Sanctuary, west of Los Angeles, a site specifically chosen as a location to explore NOAA's operational objectives with the DCS and EO/IR sensors.

In the following two weeks, two attempts were made to conduct a 20-hour flight over the Pacific Ocean. During both flights, problems occurred with the satellite communications link that required the aircraft to return to base, limiting the flight duration to less than seven hours. Flights began again on 14 November with an 18.4-hour flight over the Pacific Ocean (Figure 3). This flight included descent and ascent altitude profiles at two fixed locations off the coast of Californi a; one near Vandenberg Air Force Base and the other near Trinidad Head (41°N, 124°W). The ability to conduct altitude profiles at remote locations was a key aspect of the Altair demonstration. The final project flight of 7.7-hour duration occurred over the Channel Islands on 16 November.

Sampling Results

The payload instruments worked almost flawlessly on the test and mission flights. The combination of flights over the Pacific Ocean and Channel Islands provided all instruments sufficient opportunity to demonstrate their value to mission objectives. For example, the gas chromatography/ozone photometer (GC/OZ) instrument observed the expected gradient in long-lived species between the stratosphere and troposphere and found evidence of a stratospheric intrusion event near the tropopause on one flight. The GC/OZ data over the Pacific Ocean will be used to help validate measurements of the same gases made from the NOAA Trinidad Head site (http://www.cmdl.noaa.gov/obop/thd/) and by the Aura satellite (http://aura.gsfc.nasa.gov/). The PMVS instrument was able to obtain signals from features of an atmospheric river on part of the May ocean flights. The ocean color sensor obtained substantial data at cruise altitudes and in a spiral descent and ascent over a calm ocean surface.

The DCS successfully mapped Anacapa Island (http://uav.noaa.gov/altair/data/anacapa_mosaic_sm.jpg) and coastal segments of two larger Channel Islands. The EO/IR sensor images were distributed as streaming video over the Internet during the flight to a pre-selected audience of interested users. Aggregations of California sea lions and northern elephant seals and approved fishing and diving activities were observed at several Channel Island locations. Large commercial ships were spotted and successfully identified by vessel type from up to 16.1 kilometers away. During flight, the REVEAL system created aircraft status displays and three-dimensional maps of the Altair location.

Altair operated in both restricted and controlled areas of the National Air Space (NAS). Obtaining permission for Altair flights from the U.S. Federal Aviation Administration (FAA) was an important success of this demonstration project because of the location and complexity of proposed flight plans. The FAA and its regional centers on the U.S. west coast were cooperative regarding flight plan approval and in-flight coordination with Altair. In August 2005, the FAA granted Altair the first 'experimental certificate' for a UAS, which provides increased freedom for Altair to operate in the NAS (http://www.ga.com/). The 'experimental' marking on Altair can be seen in Figure 1. The certification is notable recognition of the quality and reliability of Altair operations and encouragement for expanded development and use of UAS technology in the NAS.

The Way Forward

With the Altair demonstration flights completed, work will focus on the interpretation and publication of the datasets. As a result of this project, NOAA has formally recognized the important role that Altair and related technology will play in NOAA's future by initiating a program to develop and direct UAS activities. A variety of UAS activities and collaborations are underway or planned. NOAA-planned Altair activities include a collaboration with NASA and the U.S. Forest Service on the Western States Fire Mission in 2006 and with NASA on the Aura Validation Experiment in 2007.

Additional ormation about the UAS program is available at http://uas.noaa.gov and http://www.uav.com/

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Reevaluating Hubbert's Prediction of U.S. Peak Oil

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In 1956, M. King Hubbert, chief consultant for the Shell Development Company's exploration and production research division, forecasted that U.S. oil production would peak in the early 1970s. He subsequently updated this prediction using newer data, but the predicted timing of peaking did not change significantly (see *Hubbert* [1982] for a review and references to earlier papers). In 1971, U.S. annual production of crude oil peaked at slightly more than three billion barrels (bbl).

Yet, Hubbert's model continues to be challenged by some. For instance, according to economist Michael Lynch, president of Strategic Energy and Economic Research, Inc., Winchester, Mass., it was only after Hubbert published his predictions "that the Hubbert curve came to be seen as explanatory in and of itself, that is, geology requires that production should follow such a curve" [*Lynch*, 2003].

This assertion is not supported by the geological literature. Long before Hubbert, geologists had pointed out that mining production follows a pattern of boom and bust:

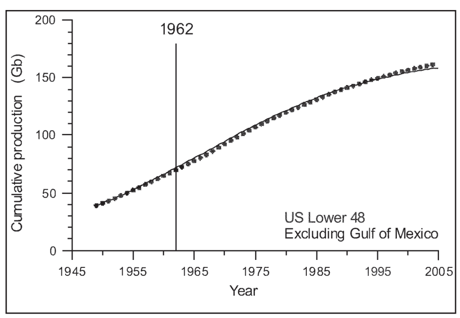

Fig. 1. Cumulative oil production in the lower 48 states (dotted curve), excluding production from the Gulf of Mexico, compared with the predicted trend (solid curve) obtained in 1962 by Hubbert based on production data to the left of the vertical line.

slow initial production preceding rapid growth as readily available resources are mined, followed by peak production and slow decline as remaining resources become more difficult to harvest. In 1889, geologist Edward Orton, after conducting a survey of the oil and gas resources in northwestern Ohio, warned that the local boom could not last long because "we are drawing upon a definite stock of this substance" [*Orton*, 1889].

It has been long recognized that geologic constraints are not the sole factor driving the production cycle. *Hewett* [1929], for example, discussed the importance of technology, economics, and political factors, which may influence the precise nature of the production curve. The recent surge in oil prices has resulted in increased interest in what used to be considered unprofitable oil resources, and fields previously considered uneconomical are now being exploited. Nevertheless, the primary driver of the cycle of mining production is the limited availability of the resource being mined. Without understanding these concepts, there would have been no reason for Hubbert to consider peak production and subsequent decline; the U.S. data available at the time (1956) applied to the period of rapid growth and by themselves showed no sign of an impending peak.

Much of the criticism revolves around Hubbert adopting the logistic model or bell-shaped curve. Hubbert recognized that production need not be symmetric but espoused the logistic model, which yields a parabolic curve for production rate, dQ/dt, as a function of cumulative production, Q, because this symmetry was dictated by the U.S. oil production data, not because of some a priori assumptions. Stressing this point, *Hubbert* [1982] wrote that, "it is to be emphasized that the curve of dQ/dt versus Q does not have to be a parabola, but that a parabola is the simplest mathematical form that this curve can assume. We may accordingly regard the parabolic form as a sort of idealization for all such actual data curves, just as the Gaussian error curve is an idealization of actual probability distributions."

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